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FLUCTUATIONS IN GEOPHYSICAL AND BOUNDARY LAYER FLOWS.(U)
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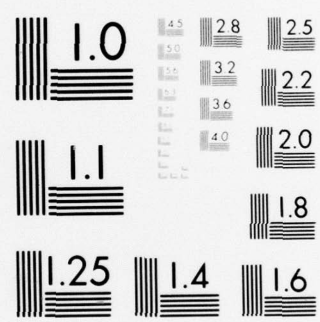

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Final Technical Report

Grant # AFOSR - 74-2579-E

1 Aug 73 - 31 July 1978

FLUCTUATIONS IN GEOPHYSICAL AND BOUNDARY LAYER FLOWS

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Seattle, Washington 98195

20 October 1978

Abstract

The study of fluctuations in geophysical-type flows is the central issue of the work pursued under the auspices of this proposal. By appropriate model~~l~~ing, an understanding is sought for (1) the processes that control and originate the transfer of energy, momentum, or mass in the atmosphere and (2) large-scale instabilities in both ordinary and atmospheric boundary layers. Besides investigating transition conditions, general effects of body forces (rotation of the earth in this case) on turbulence generation in such a shear flow are explored.

Review of Investigation Progress

Basically, the means for researching the type of phenomena that occurs in atmospheric or boundary layer conditions rests with some form of a stratified shear layer. Given such a flow--and it is assumed that it is defined well enough so that all major mean physical characteristics are known and even describable analytically--general linearized perturbation theory is utilized for probing these flows with the ultimate methods employed for solution of the perturbation field being a blend of analytical tools and numerical computations.

A. Stratified Shear Flows

With the specific case of atmospheric conditions, a series of important steps has been followed for the exploration. First, proper modelling of the most useful mean flow(s) was developed. Such effort yields a workable mean velocity profile $\bar{U}$ and density $\bar{\rho}$. Second, this system was perturbed to test the equilibrium for stability and the critical relationships of the physical parameters involved. Typically, this step involves boundary conditions, Reynolds and Richardson numbers and is fully three-dimensional. Third, initial-value problems were considered and solved with emphasis on developing wave packets. This action provides a means for determining the development of known fluctuations within this environment. A means for eventual breakdown has already been proposed. (Cf. M. T. Landahl and W. O. Criminale, *JFM*, 79(3):481-497,1977.)

Under this plan, two specific different kinds of flow have been analyzed with quantitative treatment: (a) a stratified shear layer in the absence of boundaries; (b) stratified shear layer with a solid boundary at the bottom extremity. In both cases, the perturbation equations are considered inviscid (a step justified by the fact that there are dynamic instabilities present in the system) in addition to being linear. The general initial-value problem

bases have been established with the complete solution depending upon both normal mode expansions (exponential time behavior from the homogeneous system) and a series of source-like and doublet-like distributions for the particular part of the solution(s). This means that the differential equation that must be solved can be written in operator form as

$$(\bar{U}-c)^2 \; L(\hat{w}) = 0$$

where $\bar{U}$ is the mean velocity, c is the complex phase velocity of the perturbation and L is an ordinary operator involving second derivatives on the normal component of the perturbation velocity. When represented in this manner it is clear that there are three sets of solutions:

(i) $L(\hat{w}) = 0$ Regular normal modes governed by the homogeneous equation and overall stability results.

(ii) $L(\hat{w}) = \delta(z-z^*)$ Particular solution due to source-like terms.

(iii) $L(\hat{w}) = \delta'(z-z^*)$ Particular solution due to doublet distribution.

The last two sets of solutions are not usually considered in stability theory but must be determined for a complete set of solutions in order to expand any arbitrary initial conditions. It is not sufficient to use only the part due to the homogeneous equation.

A unit pulse is introduced into the flow initially (any other arbitrary given distribution would be a linear combination of this case and, in wave space, no scale is biased) and the subsequent motion picture is determined over three relevant intervals of the time, namely, early, intermediate, and asymptotically. Early time development is obtained by a simple Taylor series expansion in time and the results become spatial alterations of the initial distribution indicating the immediate re-distribution. Intermediate time

depends upon inversion of the Fourier decomposition by numerical computation. The critical final period resorts to ray mathematics but with the caution of doing the calculations correctly because the system is non-conservative. If this care is not taken, spurious results, such as developing caustics can come about that have no physical bases whatsoever. Along the way of this extensive exploration spatial, as well as temporal growth or decay of an initial perturbation, has been considered. A specific example as shown in Figures 1 and 2 illustrate the kind of differences in the techniques. This example is for the flow with a solid boundary at the bottom level.

A report giving the details of ray mathematics in non-conservative systems has been completed (M. Gaster, *Geofluiddynamical Wave Mathematics, Research Contributions*, Applied Mathematics Group, University of Washington, 1977) and a Ph.D. dissertation ("Initial-value problems in stratified shear flows," J.E. Bradt, Department of Oceanography, University of Washington) covering the entire subject will be ready this year. Publishable versions of the work will follow soon thereafter.

B. Boundary Layers

Two major aspects of the atmospheric boundary layer have been considered. First, an initial-value problem in the laminar non-stratified Ekman layer has been done within the type of framework given for atmospheric shear flows. Actual calculations were made for a series of time steps for three different Reynolds numbers (chosen so that the range of unstable modes could be incorporated and examined). It can be recalled that there are two major viscous instabilities (Parallel and Tollmien-Schlichting) and one inviscid due to inflexions in the mean velocity profile. Many details are necessary for completion of this work--eigenvalue calculations, double Fourier integral

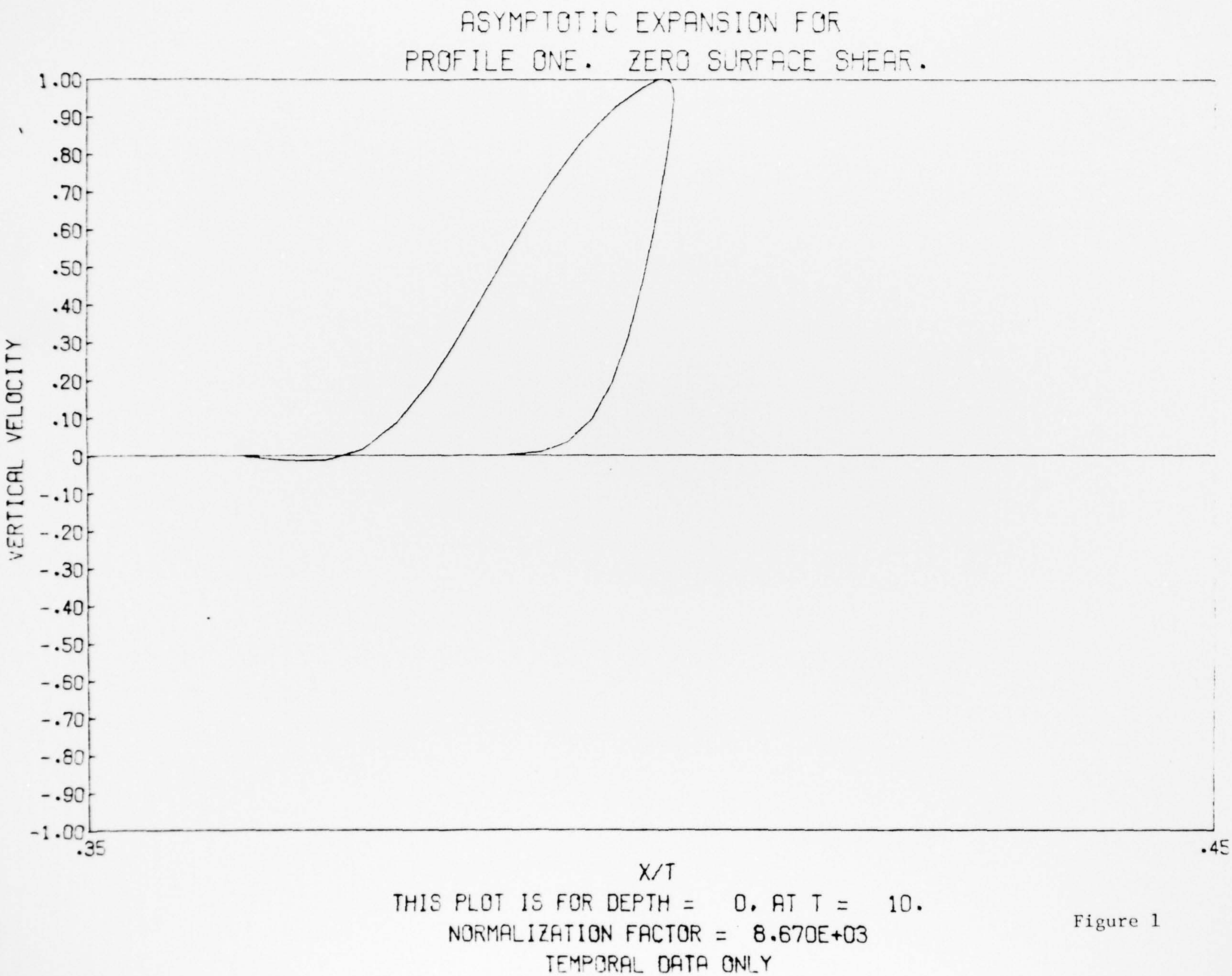
inversions, and a means to display results. One final product is included here in Figure 3 for the Reynolds Number = 105 and at a time very much after the initial pulse. It is clear that the wave packet is beginning to separate and the two prominent viscous modes (Parallel and Tollmien-Schlichting waves) are both present and distinct.

The second part of this work involves the turbulent Ekman boundary layer. Simple formulation has been made by allowing a variable eddy viscosity with a logarithmic velocity layer connected (as one moves from the boundary to the free-stream) to an Ekman spiral. Perturbation calculations tend to indicate that the layer is stabilized with respect to all the possible physical modes of instability. In a gross way, then, it appears that turbulence production in this kind of flow is akin to a classic boundary layer without rotation. Indeed, except for certain necessary unique features, the physics may be the same. Moreover, linear calculations can be used to further study the problem. For example, velocity-velocity cancellations can be estimated in a manner analogous to Landahl's proposal (M.T. Landahl, *JFM*, 29(3):441-459, 1977).

A complete Ph.D. dissertation ("Fluctuations in the atmospheric boundary layer," G.F. Spooner, Department of Oceanography, University of Washington) covering the work on both the laminar and turbulent problems will be completed during 1979.

Newer techniques on laminar boundary layers of the flat-plate variety are also under investigation with two topics considered important: (a) is there a continuous spectrum of eigenvalues (or, in other words, a temporal solution(s) that is not described by the normal mode expansions?) in addition to the known discrete set and can such a spectrum be calculated in a manner that is not involved, i.e., without some form of the Orr-Sommerfeld equation; (b) is the general perturbation problem that is being considered correct, i.e., is it adequate that the Blasius solution is perturbed? Both of these

investigations are in an advanced state but not yet ready to be reported because necessary numerical computations remain to be made.



ASYMPTOTIC EXPANSION FOR
PROFILE ONE. ZERO SURFACE SHEAR.
VERTICAL VELOCITY
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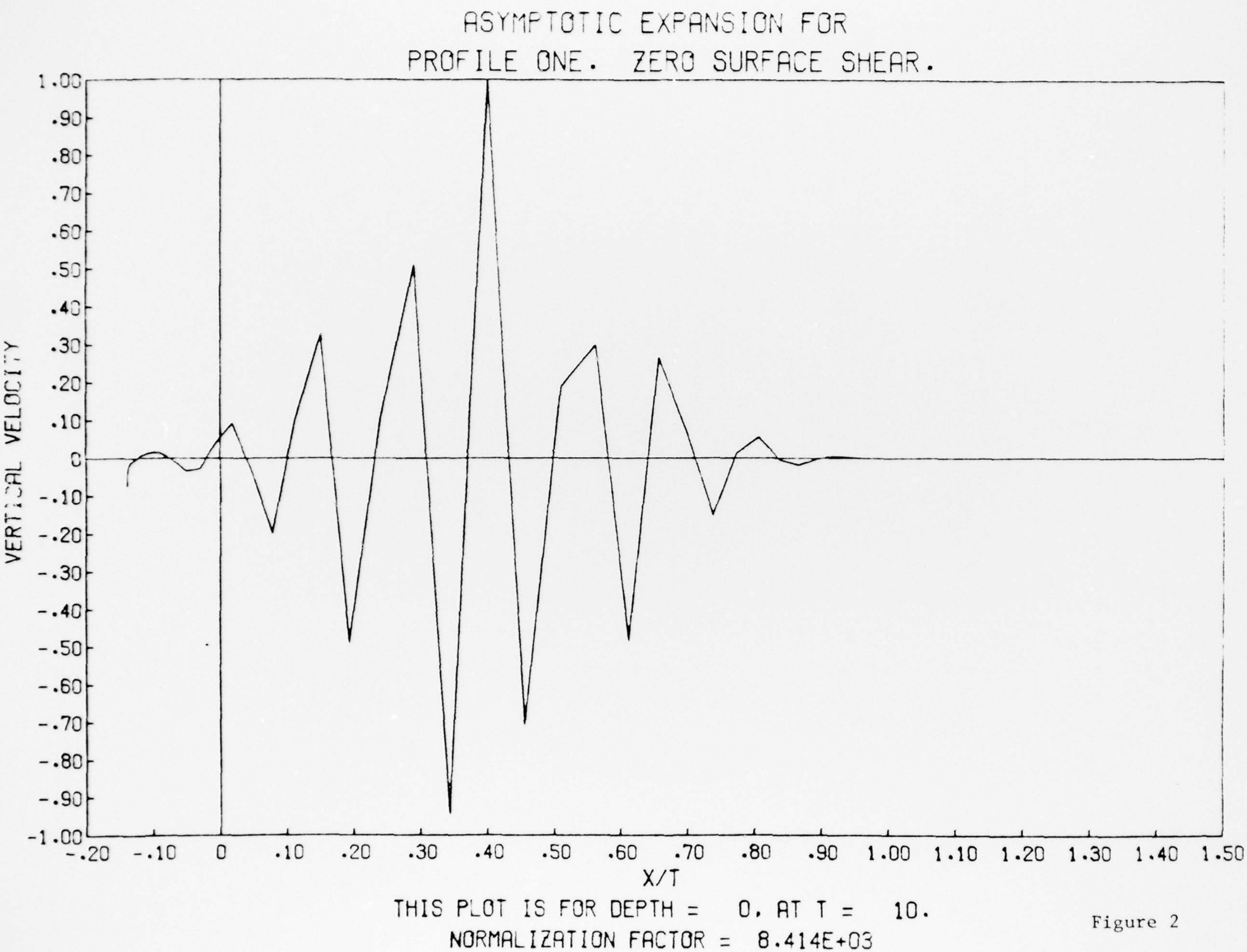
X/T
THIS PLOT IS FOR DEPTH = 0. AT T = 10.
NORMALIZATION FACTOR = 8.670E+03
TEMPORAL DATA ONLY

Figure 1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X/T
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NORMALIZATION FACTOR = 8.414E+03

Figure 2

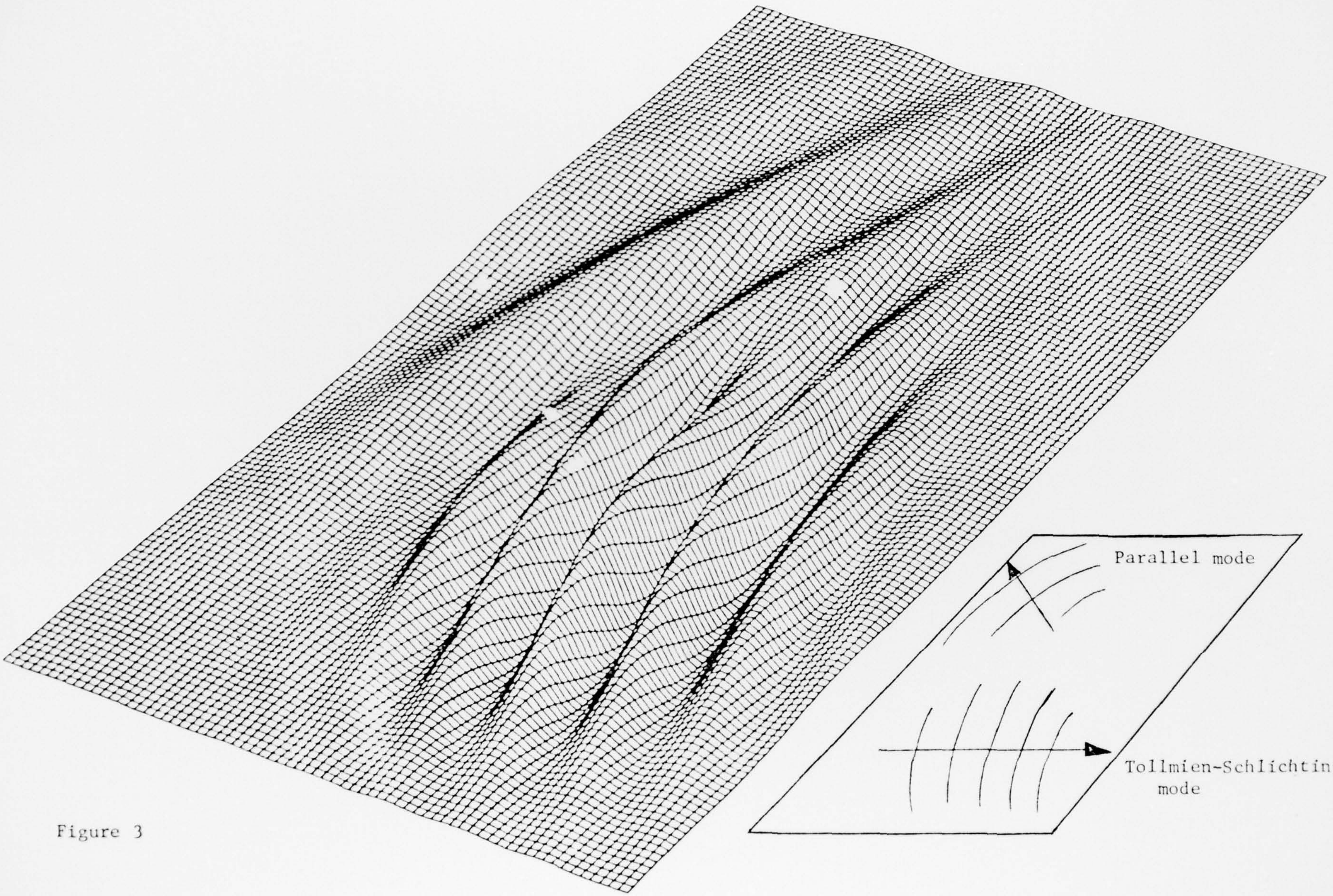

Figure 3

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STRATIFIED SHEAR LAYER

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

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